water

Review

Wastewater Management in Agriculture

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Abstract: Considering the global climate changes that have disrupted the availability of fresh water and led to the emergence of drought, an effective management strategy for water quality must be implemented. In this work, we analyzed the possibility of used and treated water being reused and the effect of its use on soil on the development of plants. In the case of irrigation with treated wastewater, the following parameters increased: calcium carbonate equivalent, organic matter, content of phosphorus, calcium, potassium, sodium, nitrogen, biochemical oxygen consumption; chemical oxygen demand (COD), decreased sodium absorption rate, soil electrical conductivity, pH, magnesium content, and soil bulk density. Due to the micronutrients it contains, the use of treated wastewater in irrigation can be an organic fertilizer for the soil. Wastewater is a source of soil water supply. Untreated wastewater may contain, depending on the source (industry, pharmacies, medicine, households), toxic compounds, bacteria, viruses, and helminths, which, if used for long periods of time in irrigation, can have a negative impact on health and the environment, reaching the soil, the roots of the crops, and then the underground water. Therefore, these waters must be used after adequate treatment. Global climate change disrupts the availability of fresh water and negatively influences the occurrence of floods, droughts, and water quality, which is why any water source must be managed correctly.

Keywords: climate change; bacteria; treated water; wastewater; soil; water management

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1. Introduction

The increase in the average global atmospheric temperature by approximately 1.2 °C compared to the end of the 19th century has had a negative impact on the environment and on health [1]. Until 2019, the concentration of greenhouse gases in the EU from industry was 9.10%, from agriculture 10.55%, from waste management 3.32%, from energy 77.01%. The objectives of the European Union regarding a reduction in pollutant emissions are that, by 2050, they should be zero, and by 2030, they should be reduced by 55% [1].

Taking into account the fact that global climate change disrupts the availability of fresh water and negatively influences the occurrence of floods, droughts, and water quality [2], solutions must be found to treat wastewater [3]. Human and industrial activities have altered the quality of water resources, especially in the last 50 years, and pollution has had an impact on most water bodies on the globe; therefore, any water source must be managed correctly, and an effective quality management strategy must be implemented for the water [2]. Moreover, Pehme et al. [4] confirmed that organic and nonorganic pollutants from landfills are a source of groundwater pollution [4].

Considering the lack of water in many countries, in this paper, we have analyzed the possibility that treated wastewater can be used for soil and crop irrigation.

According to meteorological forecasts, by 2100, the average global temperature will increase by 3.5 °C compared to the pre-industrial period, which will lead to drought and wildfires, which will affect the environmental compartments, making it necessary to exploit any source of water [3]. Water from rivers supplies many regions of the globe, and it is vitally important, considering that the amount of water from rivers represents 0.0001% of available water [5].

The estimated population growth of 8.6 billion in 2030 and 11.2 billion in 2100 [6] will also facilitate an increase in the need for food and natural resources from agriculture [7]. Due to the agricultural drought caused by a lack of precipitation as a result of climate change, many agricultural areas would be reduced, and thus the production of crops decreased [8].

Many European countries are facing water stress, as evidenced by the conversion ratio from the total water extraction of a country to all renewable freshwater resources, highlighting the pressure exerted on water resources. Figure 1 shows the water stress index for each country [9]. High water shortage occurs when there are water losses greater than 75% of the renewable water resources; when water losses are greater than 60%, we have water shortages; when losses are over 25%, we have water stress. Extremely high water stress values greater than 80% are found in the following countries: Libya, Israel, Egypt, Jordan, Saudi Arabia, Turkmenistan, and Uzbekistan. Water stress is considered high for values in the range of 40–80%, affecting China, India, Afghanistan, and South Africa. Countries with low–moderate water stress (10–20%) are the United States and Kazakhstan; South America, Canada and Russia have low water stress (<10%).

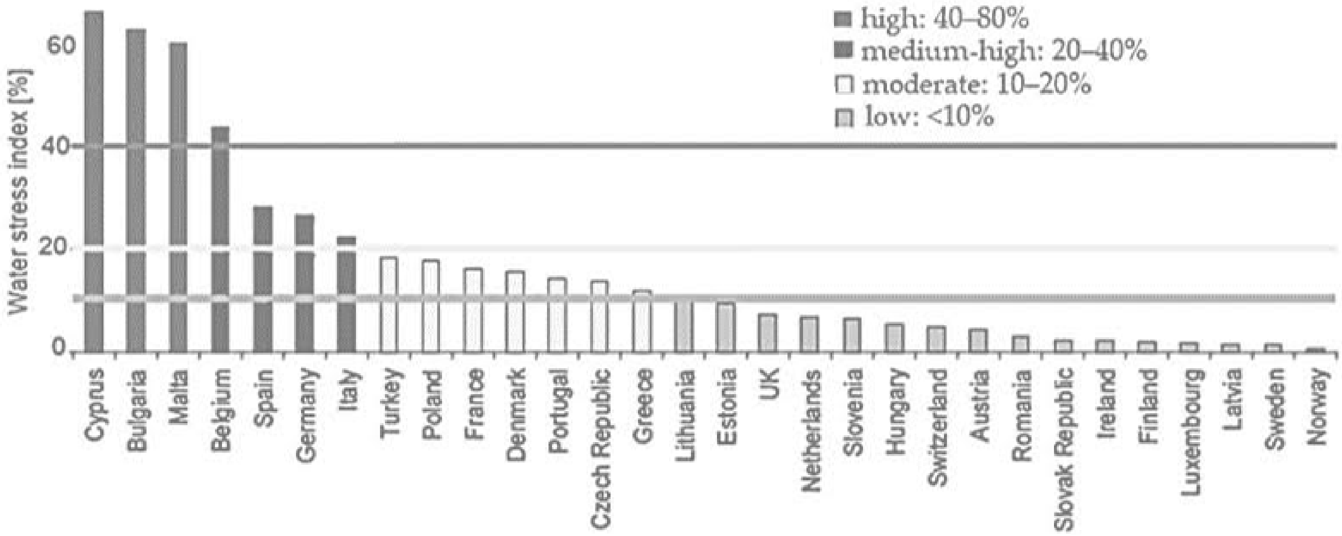

Figure 1. Water stress index for European countries (adapted from [2]).

Arid areas are affected by water stress.

According to studies carried out by Engin and Demir [10], there are no wastewater treatment plants in underprivileged areas due to their high price [10].

The uncontrolled discharge of municipal and industrial wastewater pollutes the environment [11].

Improving water reserves by reusing wastewater is a solution to the existing water deficit due to drought that would help increase water reserves for agriculture and to thus fertilize agricultural lands [12,13]. According to [14,15], the use of wastewater in irrigation has the following advantages: it reduces the pressure on underground water resources, increases the efficiency of agricultural production, lowers costs for wastewater treatment, increases the hydraulic conductivity of the soil, increases the porosity of the soil, decreases the bulk density of the soil, decreases the pH saline soil compared to the soil that was watered with water from the river [14,15]. By treating wastewater, physical soil properties and fertility can be improved, organic matter content can be increased, soil structure improved, and the soil water storage capacity can be increased [16]. The use of wastewater for irrigation brings more nutrients to the soil than freshwater, such as nitrogen, phosphorus, potassium, and organic matter, which are able to replace chemical fertilizers, thus reinducing environmental pollution [17–19].

According Zema et al. [13], the water deficit is due to the lack of precipitation, the existence of inefficient water distribution networks, the high demand for irrigation water, and the reduced efficiency of irrigation, the deficient treatment of wastewater, and climate change [13]. The use of treated wastewater in agriculture is a method of disposing and managing wastewater [20].

The drought that has manifested itself in many countries affects energy production and reduces crop yields [5]; therefore, a sustainable management strategy for the water quantities of all hydrographic basins (rivers, dams, and underground waters), domestic wastewater and industrial, is important. Soil irrigation with untreated wastewater can affect soil quality, agricultural crops, and, depending on its origin, human health due to the content of heavy metals, suspended solids, antibiotics, detergents, and pathogenic microorganisms [21]. Industrial wastewater use can degrade soil and contaminate groundwater, as well as decrease soil hydraulic conductivity and the infiltration rate [22]. Attention must be paid to the method of treating wastewater used in irrigation to reduce the long-term effects of wastewater on crops intended for human consumption.

The harmful effects on the soil when using wastewater for irrigation depend on the type of treatment applied before reuse [23–25]. In order to have quality water [26,27], and to avoid the eutrophication of natural waters, the nitrogen and phosphorus contents resulting from industrial wastewater and from agricultural and residential activities must be reduced; therefore, the removal of phosphorus in wastewater treatment plants should be pursued [26]. According to [26], the regulation of phosphorus penetration into natural water can be achieved by climatic factors [26]. Saaremäe et al. [28] achieved a 98% reduction in phosphorus content in wastewater using Ca–Fe oxide granules. Bunce et al. [29] used the green microalgae Scenedesmus sp. and Chlorella sp. for the removal of phosphorus from wastewater [29]; phosphorus can be removed by using biochemical processes, specifically, 20–30% by primary and secondary wastewater treatment chemically and 20–40% of phosphorus by biological, physical-chemical processes [30]. Each source of water must be managed and treated [31]. According to [32], in order to evaluate the impact of climate change on natural waters, it is important to know what influence the hydrology of the watershed has on the nutrients and pollutants in the water [32].

To avoid water and soil pollution, wastewater treatment plants have been built [18]. According to the data in Table 1, the share of the population in countries that treat wastewater in treatment plants has increased to 95% in the following countries: Denmark, Germany, Luxembourg, Austria, Sweden, Switzerland, and the United Kingdom. One in two households in Malta and Croatia (in 2020) was connected to secondary urban wastewater treatment plants, and in Iceland (in 2010), Albania, Serbia (in 2020), and in Bosnia and Herzegovina (in 2019). Between 2002 and 2020, Cyprus and Portugal had an increase in wastewater treatment from 18.3% in 2002 to 82.7% in 2018 and from 27.0% to 84.6% [33].

Fifty to eighty percent of the amount of water used comes from household activities. Wastewater also comes from industries and agriculture [34], and the global amount of discharged wastewater is 400 billion m^3/year [19]. Of the water requirement in agriculture, over 70% comes from treated wastewater [19]. Worldwide, treated wastewater is used to irrigate more than 20 million ha of land [19] (Figure 2).

Table 1. Share of the population with access to urban wastewater treatment plants, 2002–2020 (%) (data from [33]).

	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020
Belgium	47.7	53.2	57.4	71.0	75.0	76.8	80.5	82.8	84.3	83.6
Bulgaria	37.8	38.0	38.8	41.4	45.1	53.9	54.8	61.8	63.7	65.1
Czechia	69.7	70.8	71.9	75.4	76.9	78.0	79.8	81.2	82.3	83.4
Denmark	88.0	-	-	-	93.4	94.2	96.3	96.8	97.1	97.7
Germany (1) (3) (4)	92.6	93.8	97.3	91.9	95.6	95.4	95.6	96.0	-	-
Estonia	71.0	72.0	78.0	84.0	79.0	81.0	83.0	83.0	83.0	83.0
Ireland (1) (4) (5) (10)	29.0	-	-	59.0	71.0	58.8	60.0	61.2	61.8	61.9
Greece (4) (10)	-	-	-	85.0	87.4	92.0	92.8	93.4	94.8	94.2
Spain	88.0	-	88.0	88.0	93.0	88.7	84.7	86.6	86.6	-
France (1)	77.3	79.5	-	-	77.7	80.2	80.4	80.5	80.2	79.9
Croatia	-	-	-	-	-	36.9	36.9	36.9	36.9	36.9
Italy (3) (8)	-	-	54.2	57.5	-	57.6	-	59.6	-	-
Cyprus (3)	18.3	28.4	29.8	-	-	-	-	-	82.7	-
Latvia	51.1	62.7	62.5	55.1	58.9	67.6	71.2	74.1	75.4	80.4
Lithuania (3)	-	-	47.5	-	63.7	63.1	69.4	73.5	75.8	77.0
Luxemburg (2) (3)	-	88.1	-	-	-	96.6	96.9	97.0	97.0	98.3
Hungary	32.4	40.2	45.3	50.0	72.8	73.5	78.1	80.4	80.4	80.9
Malta	12.9	10.9	9.3	14.6	0.0	0.0	0.0	0.0	0.0	6.5
Netherlands	98.5	98.9	99.1	99.3	99.5	99.4	99.5	99.5	99.5	99.5
Austria (1)	86.0	88.9	91.8	92.7	93.9	94.5	95.0	99.8	99.8	99.1
Poland	54.1	56.8	60.7	62.9	64.5	68.5	71.4	73.4	74.0	74.8
Portugal (2) (5) (9)	27.0	32.0	37.0	52.0	55.8	-	-	-	84.6	-
Romania (3)	-	16.9	16.9	-	22.7	35.3	38.2	43.8	48.1	51.8
Slovenia	18.4	29.3	47.6	51.1	51.6	53.7	55.6	63.2	69.0	69.3
Slovakia	-	-	-	-	-	-	-	63.6	65.7	68.8
Finland	81.0	81.0	82.0	82.0	83.0	83.0	85.0	84.0	85.0	85.0
Sweden (10)	93.0	94.0	94.0	94.0	94.0	95.0	95.0	95.0	96.0	96.0
Iceland (3)	1.0	1.0	2.0	2.0	1.0	-	-	-	-	-
Norway	-	-	-	47.9	48.3	49.5	49.9	55.7	66.8	67.9
Switzerland (3) (7)	96.0	-	97.0	-	98.0	-	-	-	-	-
United Kingdom (3)	99.0	99.0	99.0	96.9	99.5	9.0	10.0	12.5	12.9	13.8
Albania	-	-	-	-	-	42.0	49.1	56.3	60.8	61.1
Serbia	5.1	5.8	6.8	7.2	8.6					
Turkey	19.2	24.8	29.6	31.4	37.6	42.0	49.1	56.3	60.8	61.1
Bosnia and Herzegovina (10)	9.9	10.0	10.0	10.7	10.9	11.4	11.8	29.6	29.0	29.6
Kosovo * (6)	-	-	-	-	-	0.55	-	-	-	-

(-) not available (1) data for 2001 instead of 2002 (2) data for 2003 instead of 2004 (3) data for 2005 instead of 2005 (4) data for 2007 instead of 2008 (5) data for 2009 instead of 2010 (6) data for 2011 instead of 2012 (7) data for 2013 instead of 2014 (8) data for 2015 instead of 2015 (9) data for 2017 instead of 2018 (10) data for 2019 instead of 2020.
* This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

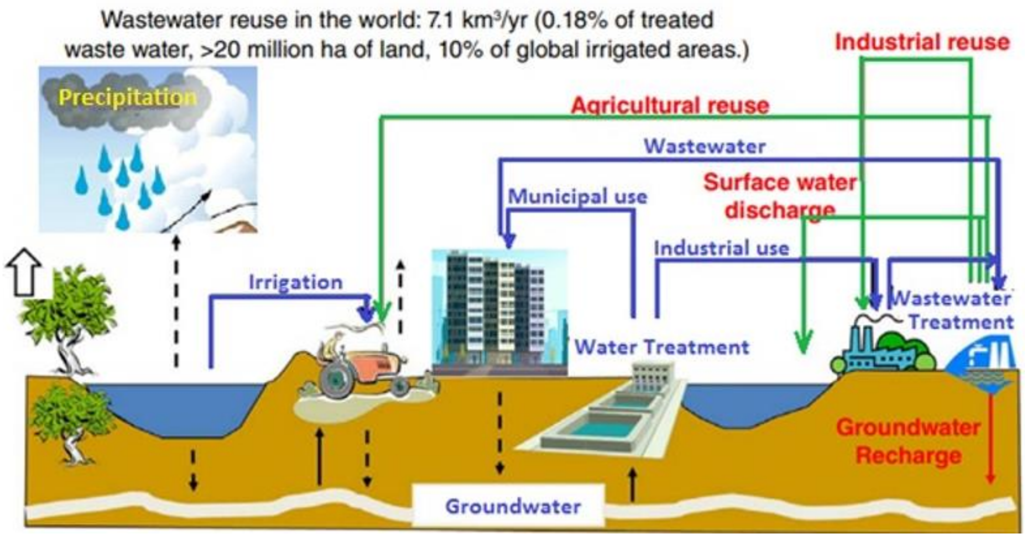

Figure 2. Wastewater reuse and the hydrologic cycle (adapted from [19]).

2. The Impact of Irrigation with Treated Wastewater on Crops

Due to the drought and a lack of water, especially in arid countries, special attention is currently being paid to the reuse of treated wastewater in irrigation. Currently, the volume of wastewater reuse has increased by 10% to 29% annually in Europe, the United States, and China, and with values lower than 41% in Australia [19,32,35]. Due to the treatment of wastewater, the percentage of its use for irrigation and drinking water has increased [36,37].

According to Rodriguez et al. [37], currently, through the implementation of wastewater treatment technologies, this water is being reused in irrigation as a source of drinking water in developed countries [37].

In Israel, the irrigation of agricultural crops is carried out at values higher than 80% of the treated wastewater [38]. In California, the quality of used water for irrigation is regulated according to standards [19]. The construction of wastewater treatment plants has increased the use of wastewater for irrigation, especially in arid and semi-arid regions.

In arid regions, wastewater and treated water are used to irrigate crops. The use of wastewater from certain industries can cause the accumulation of metals in soil, crops, and food [19].

According to the studies carried out by Qadir et al. [39], the use of untreated wastewater for irrigation can pollute the soil with heavy metals [40] from industries, which can accumulate in the upper part of the soil. For moderate levels of metals in wastewater, no special management is required if the soils are calcareous. If the soil is acidic, weeding should be carried out, avoiding the use of fertilizers and selecting crops that do not accumulate heavy metals.

In deep groundwater, it will take longer for the salts, nitrates, metals, and pathogens contained in the untreated wastewater used for irrigation to have negative effects [39]. The high content of nitrogen, potassium, and phosphorus in the soil irrigated with wastewater determines the development of the following crops: wheat, corn, soybeans, peas, cabbage, tomatoes, lettuce, alfalfa, fruits and cereals, reeds, napier grass, and canola [41–45].

According to Muchuweti et al. [46], the drip irrigation method is ecological because environmental risks can be reduced, direct contact with plant leaves is avoided, water consumption is reduced, nitrate leaching rates can be reduced [47], and contamination with pathogens and soil salinity can be monitored due to the high concentration of sodium in the effluent [18].

According to the studies carried out by Urbano et al. [18], by using the drip irrigation method of lettuce with treated wastewater compared to drinking water, the concentrations of the following nutrients from the soil increased: potassium, calcium, aluminum, nitrogen, and sulfur. E. coli bacteria were not detected on the leaves of lettuce, the physical properties of the soil were not affected, and the production of lettuce was higher on the soil irrigated with treated water compared to the soil irrigated with drinking water [18]. Moreover, Souza et al. [18] highlighted the benefits of using drip irrigation with treated wastewater in sewage treatment plants over the sprinkler irrigation method.

The use of wastewater treated at treatment plants in irrigation can replace the use of inorganic fertilizers due to its nitrogen and phosphorus content compared to drinking water, producing quality crops [48–52].

Wastewater irrigation is frequently used in underdeveloped, arid, and semi-arid countries [53,54].

A lot of biomasses were obtained by irrigating energy crops and reeds with wastewater [55].

Green onions, dried onions, and lettuce can be irrigated with wastewater [56]; when irrigating tomatoes with wastewater from the food industry [57], no pathogens were found. Moreover, the reuse of wastewater from the food industry for the irrigation of agricultural crops is available without increasing the health risk related to microbial quality [57].

By irrigating with wastewater treated at a treatment plant, spinach [56], carrots [58], radishes [59], cucumbers [60], eggplant [50], tomatoes [50], and rice [61] had an optimal development. Mandarins [62], bananas [63], lemons [64], apples, and nectarines [65] all had reduced species of bacteria.

According to the studies carried out in the paper in the work [2], untreated wastewater should not be used to irrigate vegetables, but only for fodder crops and fruit trees. Before harvesting crops, irrigation with wastewater should not be used.

3. The Impact of Irrigation with Wastewater on the Soil

The main source of water pollution in some countries [66–69] is represented by wastewater [59].

According to [70], the irrigation of tomato and broccoli crops with agro-industrial wastewater to which secondary and tertiary purification and ultrafiltration treatments and disinfection UV radiation were applied did not affect the soil quality and growth of these crops. The irrigation method was by drip so that the plants did not have direct contact with the water, thus avoiding possible contamination with pathogenic bacteria and reducing the amount of water used; these wastewaters are no longer being discharged into the natural waters and are protected (Table 2) [70]. According to Arast et al. [16], wastewater used for soil irrigation, depending on its origin, can have harmful hydrological and physico-chemical effects on soils and can modify soil properties in the short or long term [16]. The impact of wastewater irrigation on hydraulic conductivity and on the physico-chemical properties of the soils should be studied in comparison with non-irrigated soils or soils irrigated with clean water and with underground water. The content of phosphorus, potassium, organic matter, calcium, and sodium must be analyzed.

Table 2. Quality indicators of purified and potable wastewater used for irrigation (data from [41,59,70]).

Parameter	TW [41,53]		UW [41,53]		TTW [70]	SW [70]	RW [70]	WHO [59]
pH	7.45 [59]	7.9 [41]	7.89 [59]	7.2 [41]	7.5 ± 0.5	6.8 ± 0.4	5.7 ± 0.5	6–9
EC, dS/m	2.15 [59]	2.3 [41]	3.510 [59]	0.8 [41]	2.7 ± 0.5	2.7 ± 1.1	2.8 ± 0.7	0–3
SAR meq L^{-1}	7.27 [59]	-	13 [59]	-	NM	NM	NM	0–15
TDS (mg/L)	764.55 [59]	2157 [41]	1612 [59]	1469 [41]	NM	NM	NM	0–2000
SS (mg/L)	130.55 [59]	-	0 [59]	-	15.7 ± 4.9	26.6 ± 14.6	249.1 ± 89.3	10
COD (mg/L)	17.14 [59]	59 [41]	10 [59]	34 [41]	37.7 ± 14.5	40.6 ± 16.9	985.3 ± 321.6	0.5
BOD (mg/L)	2.8 [59]	32 [41]	0.8 [59]	18 [41]	37.7 ± 14.5	23.1 ± 1.3	-	100

SAR: sodium adsorption ratio; EC: electrical conductivity; TDS: total dissolved solids, suspended solids (SS), BOD: biochemical oxygen demand; COD: chemical oxygen demand. TW—treated water, UW—underground water, RW—secondary treated wastewater, TTW—tertiary treated wastewater, SW—secondary treated wastewater.

Mirzaei-Takhtgahi et al. [71] and Andrews et al. [72] found that the bulk density of soil irrigated with wastewater decreases due to the formation of soil aggregates.

The use of treated wastewater in irrigation improved all soil characteristics. The following parameters increased: equivalent calcium carbonate, soil organic matter [73], content of phosphorus, calcium, potassium, sodium, total inorganic nitrogen, bio-chemical oxygen, and chemical oxygen demand. The sodium absorption rate, soil electrical conductivity, pH, and magnesium content decreased [74]. Soil electrical conductivity (salinity) is a cause of agricultural soil degradation because it leads to swelling and the dispersion of soil aggregates [2].

The increase in the number of organic materials in a land irrigated with wastewater compared to the agricultural soil irrigated with groundwater can be related to the large number of organic materials in the wastewater used for irrigation [17,73].

High temperature values favor the development of human pathogens in water [59].

Table 2 shows the following parameters of the treated wastewater and groundwater used for irrigation: sodium adsorption ratio (SAR), soil electrical conductivity (EC), pH, dissolved solids content (SS), biochemical oxygen consumption (BOD), and chemical oxygen demand (COD).

The recommended pH values for irrigation water are between 7 and 8.5; any pH value that does not fall within this range indicates the inadequate quality of the irrigation water [17,59]. The evaluation of fresh and used water for irrigation is performed according to the standards of the World Health Organization (WHO) [75–77].

As can be seen, the pH values of the water are in accordance with WHO standards. EC electrical conductivity had higher values in the case of underground water (3.510 dS/m) compared to treated wastewater [35,78,79]. Soils irrigated with treated wastewater had higher electrical conductivities due to the presence of dissolved solids in the soil compared to soils irrigated with ground water [41,80,81]; moreover, lower electrical conductivity values were also found when irrigated with wastewater [82,83]. Nutrients (NO_3, phosphorus, calcium, potassium) are found in wastewater, which help the development of plants.

The combination of treated wastewater with well water has a better quality than treated wastewater [63]. The content of macroelements, microelements, and anions were higher in the case of irrigation with wastewater; however, it did not exceed the optimal values (Table 1).

When wastewater is used for soil irrigation, attention must be paid to the pH value so as not to acidify the soil salinity, and suspended solids in the soil should not be high in regard to the content of the organic matter and macronutrients [79]. The increase in nutrients and metals in the soil can be due to the decrease in the soil pH value [78,80]. The high pH values of the soil irrigated with wastewater can influence the decrease in soil nutrients, namely, nitrogen, phosphorus, potassium, zinc [22], which can favor the accumulation of organic matter on the surface of the soil, such as black alkali [22].

According to [83] the high concentration of sodium can cause the swelling of the irrigated soil for long periods of time when wastewater is used [36].

Irrigation of the soil with untreated wastewater for a long period of time affects the physical, chemical, and hydraulic characteristics of the soil, decreases water infiltration into the soil and hydraulic conductivity by clogging the pores of the soil at the surface with suspended materials, and reduces the bulk density of the soil [36]. The porosity of the soil irrigated with wastewater was reduced from 40% for the soil irrigated with tap water to 24% for the soil irrigated with wastewater [22].

3.1. Analysis of Metals in the Soil as a Result of Irrigation with Wastewater

The accumulation of metals in the soil is influenced by the following factors: pH, cation exchange capacity of the soil, concentration of metals in wastewater, soil texture, and duration of irrigation. According to Habibi et al. [17], the concentration of heavy metals in the soil irrigated with wastewater exceeds the permissible limit in 10–50 years. Soil iron density increases after five years of wastewater irrigation, and iron, zinc, manganese, copper, nickel, and lead concentrations increase after 20 years [73].

Table 3 shows the number of metals and micronutrients in soils irrigated with fresh water and wastewater. It is observed that the use of wastewater for soil irrigation led to an increase in the concentrations of iron, copper, zinc, and manganese. The high concentration of ammonium in wastewater causes its accumulation in the soil, and hydrogen ions from ammonium can lower the pH of the soil, thus helping the development of crops.

Table 3. The concentration of nutrients and metals in soils irrigated with fresh water and wastewater (data from [17,41,59]).

	Wastewater		Freshwater		WHO [59]
Fe, mg/kg	9.02 [17]	1.58 [54]	1.96 [17]	-	-
Cu, mg/kg	1.14 [17]	0.050 [54]	2.98 [17]	-	-
Zn, mg/kg	18.3 [17]	NM	7.92 [17]	-	-
Mn, mg/kg	10.54 [17]	0.096 [54]	7.76 [17]	-	-
Ca^{++} (mg/L)	61.15 [59]	54 [41]	54.28 [59]	15 [41]	400
Mg^{++} (mg/L)	11.51 [59]	21 [41]	27.66 [59]	9 [41]	60
Na^{+} (mg/L)	43.53 [59]	119 [41]	83.76 [59]	26 [41]	900
K^{+} (mg/L)	6.5 [59]	22 [41]	3.89 [59]	5 [41]	0–2
Fe^{++} (mg/L)	1.58 [59]	167 [41]	0.018 [59]	72 [41]	5
Mn^{++} (mg/L)	0.096 [59]	86 [41]	0.002 [59]	23 [41]	0.2
Cu^{++} (mg/L)	0.050 [59]	37 [41]	0.079 [59]	18 [41]	0.2
Pb^{+++} (mg/L)	0.019 [59]	18 [41]	0.004 [59]	8 [41]	5
Cd^{++} (mg/L)	0.0091 [59]	5 [41]	0.0001 [59]	2 [41]	0.2
Cr^{++} (mg/L)	0.014 [59]	-	0.029 [59]	-	0.1
Ni^{++} (mg/L)	0.032 [59]	7 [41]	0.006 [59]	3 [41]	0.2
Zn	-	56 [41]	-	17 [41]	-
Co	-	23 [41]	-	4 [41]	-
NH_4^{+} (mg/L)	33.31 [59]	18 [41]	0 [59]	5 [41]	0–5
NO_3^{-} (mg/L)	23.48 [59]	-	0 [59]	-	0–8
P_3^{-} (mg/L)	6.56 [59]	-	0 [59]	-	0–2

Soil pollution with heavy metals is due to irrigation with untreated wastewater, and these metals affect agricultural crops as well [78]. Metal concentrations in purified wastewater do not exceed the limits provided in the WHO standard (Table 3) [58,77].

3.2. The Content of Pathogens in Wastewater

In wastewater, there can be bacteria, coliforms, and streptococci that endanger people's health [17,59]. According to the research carried out by Pedrero et Alarcón [63], faecal coliforms were identified in treated wastewater (Table 4), their level exceeding the maximum concentration ranges for use in irrigation water recommended by the World Health Organization (WHO, 1989).

According to the studies carried out by Singh [84], the following microorganisms can exist in wastewater:

- bacteria 1–10^{10} n/L of wastewater; depending on the amount of wastewater and the source, they can survive in water for 10–60 days, in cultures for 2–30 days, and in soil 10–70 days [84];
- helminths 1–10^{3} n/L can survive in crops for 30–60 years [84], and their eggs can live for many years in the soil;
- protozoa 1–10^{4} n/L can survive in water for 15–180 days, in cultures for 2–10 days, and in soil for 10–150 days [84];

- viruses 1–10^6 n/L can survive in water for 50–120 days, in cultures for 15–60 days, and in soil for 20–100 days [84].

Table 4. The bacteria present in the treated water and in the underground water (data from [59]).

Bacterial Count/100 mL	TW	UW	WHO
Total viable bacterial count	1.1×10^3 [59]	2.4×10^2	ND
Total coliform	962 [59]	240	1000
Fecal coliform	240 [59]	0.0	<1000
Fecal Streptococci	35–65 [59]	0.0	ND
E. coli	60 [59]	0.0	ND
P. aeuroginosa	20 [59]	0.0	ND
Salmonella	4 [59]	0.0	ND
Total Vibrio	4 [59]	ND	ND
Listeria group	4 [59]	ND	ND
Nematode (egg/L)	3 [59]	ND	1

ND: not detected. TW—treated water, UW—underground water.

These microorganisms can cause the following health problems: diarrhea, cholera, gastroenteritis, giardia, eye infections, meningitis, liver infections, malaria, heart and kidney diseases, dysentery, fever, amebiasis, giardiasis, cryptosporidiosis, respiratory diseases, skin rashes, and paralysis [84]. Helminth eggs and protozoa are very dangerous and very difficult to remove by water treatment [85]. For example, E. coli can exist in sewage contaminated with feces.

Some pathogens can survive for many years in the soil or on crop surfaces if they have a humid environment and high organic content in the soil, their inactivation being achieved by exposure to direct sunlight [34,84,86].

Bacteria have a longer lifespan in soil than on crops or in wastewater [84]. Protozoa viruses have the same survival time in soil and in water. Lettuce, root vegetables, carrots, onions, and radishes irrigated with untreated wastewater, if eaten raw, can be infected with pathogenic microorganisms. Depending on the source (industry, pharmacies, medicine, households), untreated wastewater may contain other toxic compounds such as pharmaceuticals, pesticides, fungicides, herbicides, and polyaromatic compounds, which, if used for long periods of time in irrigation, can be dangerous for the environment and health; these compounds reach the soil, the roots of the crops, and then the groundwater [87–94]. The E. coli count for leaf crops must be less than or equal to 10^4; for root crops, it must be less than or equal to 10^3 (CFU/100 mL); for drip-irrigated crops, it must be less or equal to 10^5 [80]; the number of helminth eggs (n/L) must be less than one [84].

4. Wastewater Treatment Procedures

Due to the nutrients that the wastewater contains (sodium, calcium, magnesium, potassium), it can function as an organic fertilizer for the soil [95]. Irrigation of a land area of 4000 m^3/ha with 18–60 mg/L of treated wastewater would enrich the soil with 64–248 kg/ha of nitrogen; 6–23 mg/L of treated wastewater would enrich the soil with 16–96 kg/ha of phosphorus. Moreover, 4–66 mg/L of treated wastewater adds to the soil 8–276 kg of potassium, 108–722 lg/ha of sodium from irrigation with 29–178 mg/L, 36–444 kg/ha of magnesium from irrigation with 11–111 mg/L, and 73–821 kg/ha of calcium from irrigation with 21–213 mg/L wastewater [95]. It is recommended to treat the used water so that it is not dangerous for vegetation, animals, and people [96–98].

Treatments applied to wastewater can be preliminary or pretreatments (physical and mechanical) [99]; primary (physico-chemical and chemical); secondary (chemical and biological); tertiary (physical and chemical) (Figure 3) [100].

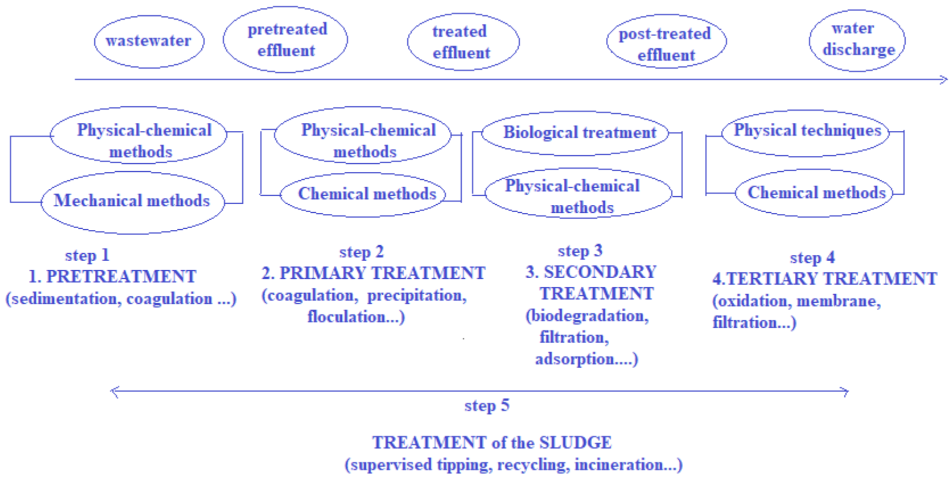

Figure 3. Wastewater treatment methods (adapted from [100]).

In the mechanical treatment of wastewater, coarse impurities are filtered, and the water is treated mechanically, wherein approximately 20–30% of the solid substances it contains are removed [100].

The water obtained after primary treatment cannot be used to irrigate crops. Water obtained through secondary and tertiary treatments is recommended for irrigating crops. Advanced treated wastewater is used for indirect drinking and the recharging of surface and groundwater bodies [84].

The elimination of pollutants can be achieved by:

- Conventional methods involving the coagulation and flocculation of suspended solids in a colloidal state or dispersed in very fine particles; chemical precipitation to remove very fine colloidal and suspended substances from wastewater by adding coagulants that make them settle; biodegradation; sand filtration; adsorption;
- Water depollution by electrochemical treatment, membrane separation, advanced oxidation, and nanofiltration [100].

Through aerobic and anaerobic treatment, certain biological micropollutants can be eliminated [101].

According to the research carried out by [102], in untreated wastewater, salinity, dissolved and suspended solids, electrical conductivity, nitrates, and trace elements did not exceed the standardized values. Nitrates exceeded the values stipulated in the standards. Before being used in irrigation, the water used with these organic micropollutants should be treated by nanofiltration [102].

According to [103], another method of eliminating pharmaceutical products from wastewater is through the use of activated carbon and ozonation. The use of anaerobic membrane bioreactors and enzymes can help to eliminate organic micropollutants from wastewater with low costs and high efficiency. In the future, it is recommended to use some economical and environmentally friendly technologies for the elimination of organic micropollutants from wastewater, such as the use of anaerobic membrane bioreactors, constructed wetlands, and different wetlands that, through processes such as pyrolysis, sorption, biodegradation, photolysis, and volatilization, can remove these organic micropollutants with an efficiency between 54 and 98%; lastly, the use of enzymes can help with low costs and high efficiency [103]. According to [104], the toxicity of water polluted with organic micropollutants was analyzed by bioanalytical tests, being applied seven wastewater treatment barriers: the source control; the wastewater treatment plant, the application of the microfiltration treatment, reverse osmosis treatment, and advanced oxidation treatment, natural environment in a tank and drinking water treatment plant (Figure 4). At each treatment stage the toxicity of the water samples was monitored and it was found that the toxicity of the water samples decreased along the seven treatment barriers, certain toxic compounds were no longer detected. Bioanalytical tests were used to evaluate the efficiency of micropollutant removal during the water treatment stages. Toxic equivalent concentrations in water samples were applied to the umuC test indicating genotoxicity. These organic micropollutants can have effects on human health as follows: cytotoxicity, genotoxicity, oxidative stress, and cellular effects on the human body, as well as protein damage and estrogenic effects. [105].

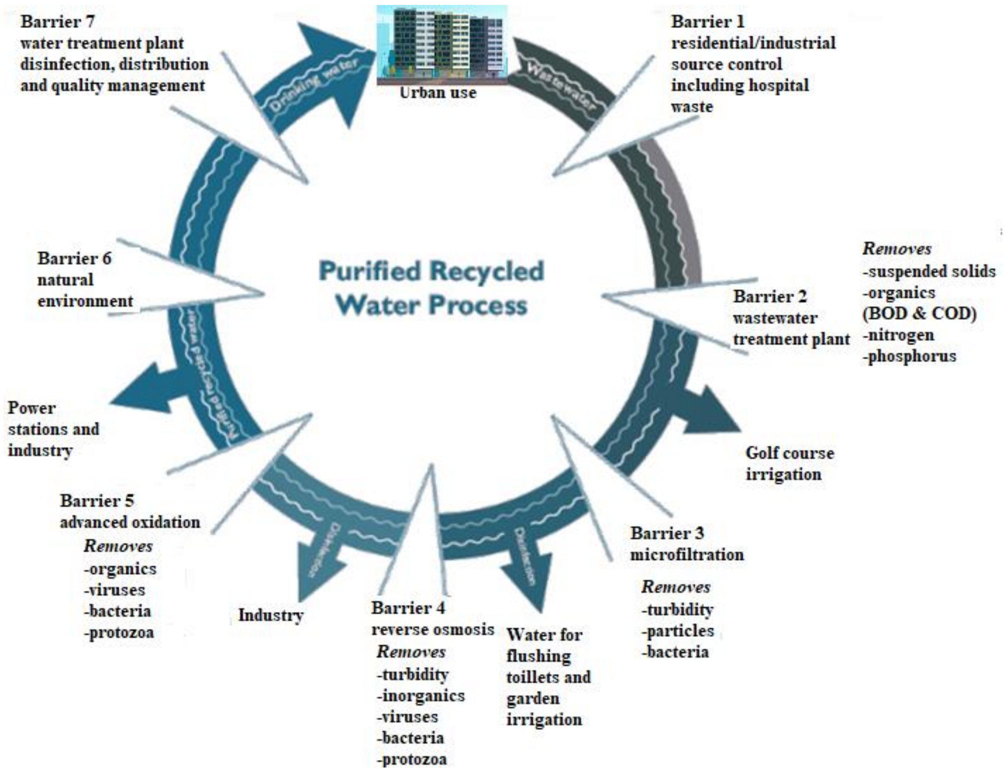

Figure 4. Treatments applied to wastewater in order to be reused (adapted from [105]).

Organic pollutants that can exist in industrial wastewater are combustion products, industrial chemicals, consumer and personal care products, biocides, pharmaceuticals, industrial chemicals, pesticides, human metabolites and environmental transformation products, combustion byproducts, water treatment by products, and natural hormones.

Through the bioanalytical tests performed on the organic micropollutants in drinking water treated with these treatments, it was found that there were no drinking water standards exceeded (Figure 5).

According to Council Directive 91/271/EEC of 21 May 1991, regarding the treatment of urban wastewater, for the purpose of its recovery, the current technologies used to remove these pollutants do not completely remove them, as they can be found in sewage sludge, causing problems when the sludge is reused in agriculture [106]. The benefits of wastewater treatment are greater than the costs, and they are conducive to a reduction in the pollutants in the treated wastewater, a positive impact on water quality, and the supply of water for irrigation in agriculture [11].

The price of treatments to eliminate pharmaceutical pollutants from wastewater is presented in Table 5.

Table 6 shows the values of the concentrations of organic micropollutants in effluents and surface waters; their values are lower in surface waters than in sewage treatment plant effluents.

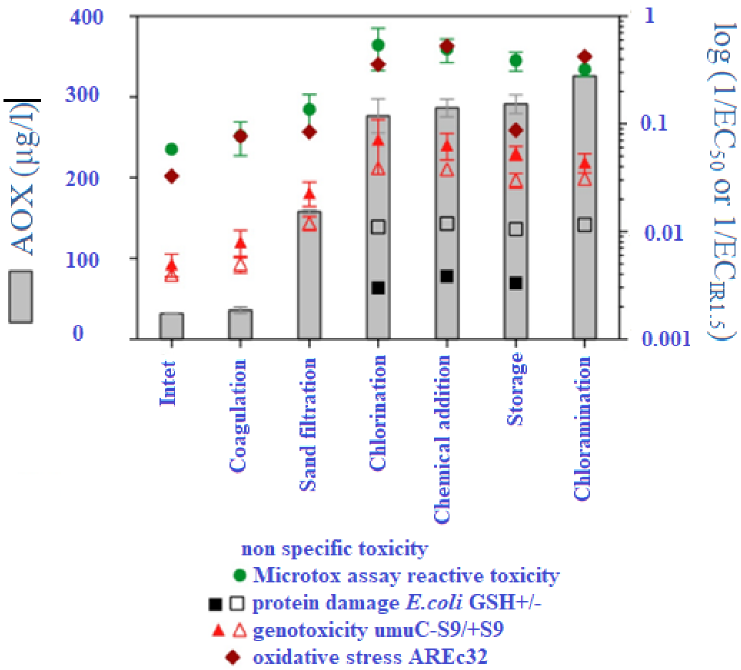

Figure 5. Bioanalytical testing of drinking water (adapted from [105]).

Table 5. The price of treatments to eliminate pharmaceutical pollutants from wastewater (data from [107]).

Treatment Method	Costs, EUR/m^3	Residues Left after Treatment, %
Conventional treatment (without micropollutants removal)	0.17	47
Ozone oxidation	0.23	2
UV radiation	0.3	13
Activated carbon	0.48	3
Reverse osmosis	0.65	4

Table 6. The values of the concentrations of organic micropollutants (data from [107]).

Compound	Concentrations in Effluents (ng/L)	Concentrations in Surface Water (ng/L)	Compound	Concentrations in Effluents (ng/L)	Concentrations in Surface Water (ng/L)
Dioxins PCDDs	0.003 ÷ 0.177	0.728 ÷ 6	Diclophenac	50 ÷ 2500	2.8 ÷ 470
Furans PCDFs	0.006 ÷ 0.05	0.599	Carbamazepine	482 ÷ 950	n.d ÷ 230
Polychlorinated biphenyls (PCBs)	10 ÷ 908 (7 congeners)	0.3 ÷ 150	Ibuprofen	81 ÷ 2100	10 ÷ 40
Nonylphenol (NP)	880 ÷ 22,690	0.8^8 ÷ 18,000	Naproxen	21 ÷ 12,500	<LOD ÷ 300
Diethyl phthalate (DEHP)	6.01×10^6 ÷ 17.04×10^6	110 ÷ 36,000	17β-Estradiol (E2	<5 ÷ 631	369
Polycyclic aromatic hydrocarbons (PAHs)	1025 ÷ 3,056,000	4–437	17αEthynylestradiol (EE2)	< 5 ÷ 187	43
MCPA	25 ÷ 150	n.d. ÷ 370	2,4-D	13 ÷ 27	<1000
Diuron	62 ÷ 1379	2.4 ÷ 2.849×10^6	Dieldrin	<10	2.5
Aldrin	Production is banned	15.3	Atrazine	no data	100 ÷ 4.9×10^5
Tributylocine (TBT)	2.5×10^6	1.39×10^3–1.44×10^3	Endosulphane	≤220	≤4×10^3

n.d.—not detected; LOD—limit of detection.

5. Conclusions

In this work, we analyzed the possibility that treated wastewater can be used in agriculture, thus ensuring water for crops and their good management, avoiding the pollution of natural waters and the waste of wastewater.

Due to its nutrient content, this treated water has led to an improvement in soil characteristics and can be a substitute for fertilizers.

The levels of heavy metals in the soil irrigated with untreated wastewater were below the values provided in the standard. The source of the wastewater must be analyzed, and the treatment of industrial wastewater is recommended.

Soil irrigated with treated wastewater has a lower electrical conductivity and sodium absorption ratio than fresh water. The use of treated wastewater does not produce a problem regarding soil salinity and alkalinity. Wastewater is a source of soil water supply. The use of wastewater for irrigation should be based on proper management [89].

The global increase in population has led to an increase in the production of wastewater which, if not purified, can pollute the soil, water, and food with the pathogens it contains. For crop irrigation, the use of wastewater treated by advanced processes is recommended [84].

The water crisis and the prolonged drought due to climate change forces us to properly manage used water and to correctly apply treatment techniques in order to be able to reuse it. The discussed problem, in relation to the need to use treated wastewater in the irrigation of agricultural crops, is constantly being researched by scientists from different regions of the world. A review article on this topic will hopefully be helpful to other researchers interested in this topic.

It is recommended to continue research on the monitoring of wastewater pollutants, the quality of effluent treated with wastewater from different sources of pollution, and the long-term effects of pollution with organic and inorganic substances on the soil, on agricultural crops, and on human health; moreover, innovative materials and nanomaterials must be developed for the elimination of hazardous substances in wastewater, and water treatment processes must be made more efficient. Greater attention must be paid to the efficient management of wastewater and the application of the best techniques for the treatment of the biosolids contained in wastewater to avoid the eutrophication of natural water.

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